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METEOROLOGICAL EVENTS IN ARIZONA
AND NEW MEXICO DURING SWAMP

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DEPARTMENT OF COMMERCE
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Preface

SouthWest Area Monsoon Project (SWAMP)

The SouthWest Area Monsoon Project (SWAMP) was a cooperative project between forecasters and scientists of the National Weather Service, the NESDIS Satellite Applications Laboratory, the National Severe Storms Laboratory, the University of Colorado's Cooperative Institute for Research in the Environmental Sciences (CIRES), Arizona State University, the University of Arizona, the Salt River Project, and the Mexican Centro de Investigación Científica y de Educación Superior de Ensenada (CICSE).

The project had three major scientific focuses: (1) Central Arizona thunderstorm environments; (2) Monsoon structures and moisture fluxes; and (3) Mexican convective systems.

SWAMP data were collected during the months of July and August 1990, using a variety of ground-based and airborne sensors. NOAA's P-3 aircraft flew several missions over Arizona and Northwest Mexico in support of the project.

All forecasting and project strategy/mission decisions were made by teams of forecasters temporarily assigned to the National Weather Service Forecast Office in Phoenix. The author served as a member of one of these teams from 16 July to 19 July 1990, inclusive.

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Abstract

New Mexico's weather, like Arizona's, is influenced by the Southwest Monsoon. Indeed, the major part of Arizona's and New Mexico's warm-season rainfall usually occurs between 1 July and 15 September. This was particularly true in the monsoon season of 1990, when both states reported several severe thunderstorm and flash flood events.

This study attempts to determine effects of the Southwest Monsoon on Arizona and New Mexico during the period from 14 June to 26 September 1990. Climatological data from both Mexico and the United States and severe storm reports from Arizona and New Mexico were the primary data sources used in this study. A key aspect of the study is to document similarities and differences between New Mexico's and Arizona's experience with the 1990 Southwest Monsoon.

Results show that the percentage of locations having measurable precipitation in a 24-hour period was greater in New Mexico than in Arizona during the 1990 Southwest Monsoon. Also, there were more "superpeak" days (TenHarkel's definition) in New Mexico than in Arizona during the period of study. Possible reasons for the difference in precipitation frequency are addressed. Precipitation patterns present in Arizona and New Mexico during the monsoon season of 1990 are also shown.

1. Introduction

My participation in SWAMP in July 1990 and the SWAMP Workshop held in June 1991 heightened my awareness of the Southwest Monsoon and its importance in shaping climate of Arizona and New Mexico. However, the catalyst for this study was John TenHarkel's presentation on the Arizona Monsoon Index at the 1991 SWAMP Workshop. His presentation persuaded me to research meteorological events in New Mexico during the 1990 Southwest Monsoon and report on them. This study is the result of that research.

2. Influence of the Southwest Monsoon

To study effects of the 1990 Southwest Monsoon on New Mexico, I had to first investigate the monsoon's long-term importance in shaping regional climate. This investigation led to the map shown in Figure 1, which shows the percentage of warm season (April to September) precipitation that occurs in July and August.

The question may arise, "Why just use precipitation totals for July and August in the numerator and warm season precipitation in the denominator to determine the areal extent of Southwest Monsoon rain?" These limits were imposed with Arizona and New Mexico in mind. By limiting the base time to the warm season, precipitation contributions from mid-latitude storms in Arizona and New Mexico was minimized.

A typical monsoon season in Arizona and New Mexico extends from late June or early July into the first half of September. However, precipitation in climatological records is usually measured in increments of months, not half-months. Also, June is typically dry over Arizona and much of Western New Mexico, except for occasional "False Monsoons" (Ingram, 1972)¹. In contrast, June thunderstorm events are common in Eastern New Mexico because of dry line dynamics, back-door cold fronts, and disturbances moving out of the Central and Southern Rockies. In late August and September, precipitation in the Southwest U. S. and Northern Mexico is often influenced by tropical cyclones or their remnants. Therefore, a "monsoon signal" can best be detected by looking only at precipitation during July and August.

Several sources of climatological data were used to construct the map shown in figure 1. These publications are listed under the heading, "Sources of Climatological Data."

Figure 1 shows that average July-August precipitation accounts for 70 percent or more of the warm season total in South Central and Southeast Arizona as well as large areas of Northwest Mexico, namely; Chihuahua, Durango, Sinaloa, and Sonora. July-August precipitation typically accounts for more than half the warm season total as far west as the mountains of Baja California, the deserts of Southern California and Southern Nevada; as far north as Southern Utah and the high mountain valleys of Central Colorado; as far east as the Central Mountains of New Mexico, the mountains of West Texas, and much of the Mexican Plateau; and as far south as Guadalajara.

¹ In the Phoenix area, False Monsoons are defined as brief, periodic increases in surface dew point temperatures to 50 degrees F or more. Full-scale Monsoon conditions are present in Phoenix when the surface dew point temperature is 55 degrees F or more for at least 72 consecutive hours.

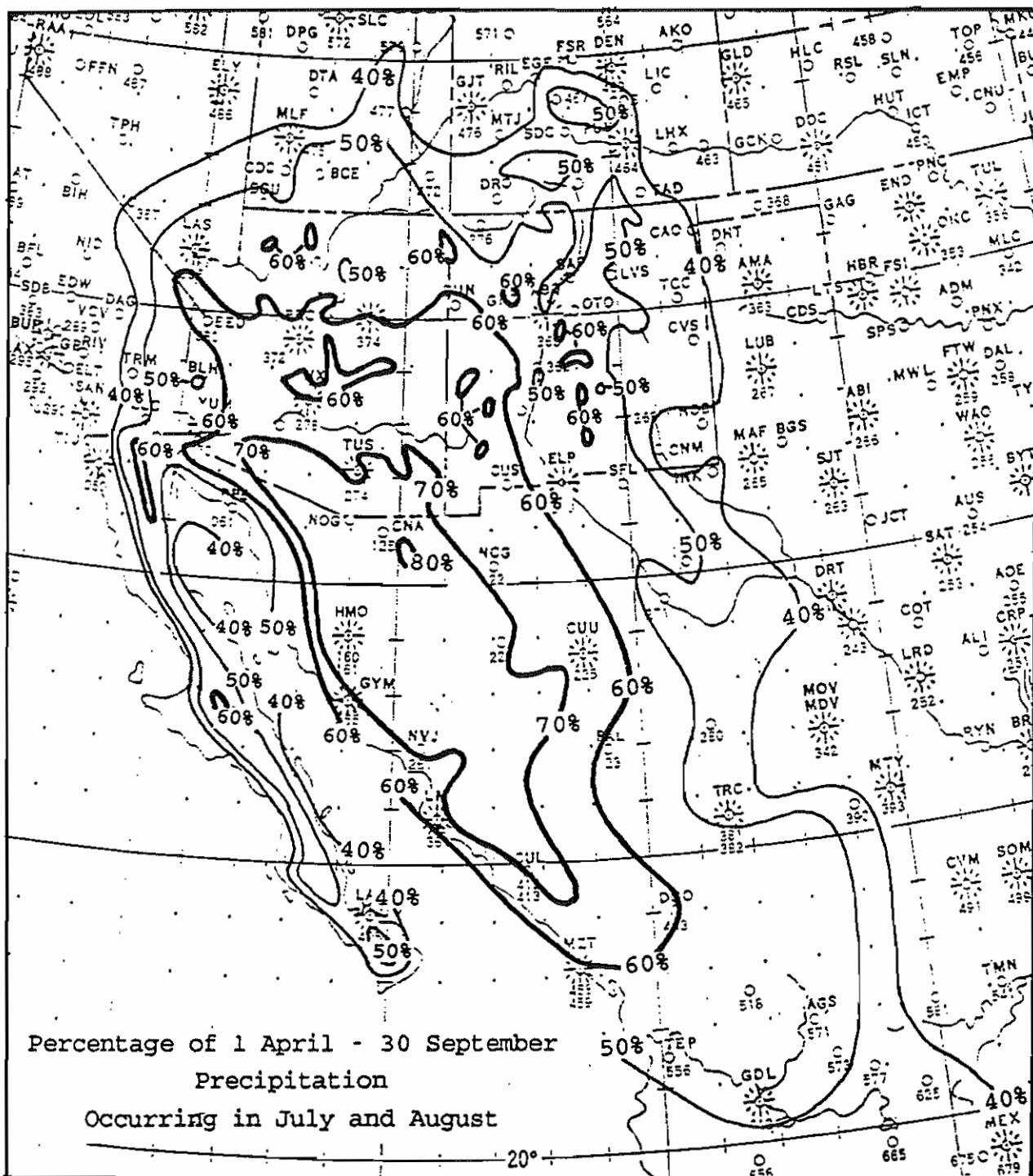


Figure 1. Map showing the percentage of warm season precipitation that occurs in the months of July and August over the Southwest United States and Northwest Mexico. Data from the publications listed under the heading, "Sources of Climatological Data," were used to construct the map.

Figure 1 also shows while most of Arizona and the western two-thirds of New Mexico have half or more of their warm season precipitation in July and August, the eastern third of New Mexico does not. A capping inversion produced by cold advection near the surface and warm air aloft can inhibit thunderstorms over Eastern New Mexico for days at a time during a typical July and August. Consequently, it seemed prudent to separate New Mexico into two areas for this study, namely east and west.

3. The Daily Precipitation Index (DPI) and DPI Zones

The *Daily Precipitation Index*, or *DPI*, is defined as the percentage of stations having measurable (0.01 inches or more) precipitation in a specified area on a given day. These specific areas are known as *DPI Zones*. The three *DPI Zones* used for this study are shown in Figure 2: They are Arizona, the western two-thirds of New Mexico, and the eastern one-third of New Mexico. The area of the *DPI Zone* in Eastern New Mexico consists of the two climatic subdivisions covering New Mexico's Eastern Plains.

3.1 The Daily Precipitation Index and the Problem of Disparate Observation Times

In the publication, Climatological Data of the States (NOAA, 1990), not all stations report their daily precipitation at the same time. In the U. S., most co-operative observers record 24-hour precipitation shortly after sunrise, late in the afternoon, or at midnight. Consequently, precipitation reported as falling on day N may have occurred on day N-1: This is especially true in Arizona and New Mexico during the warm season, when most thunderstorm rains fall between noon and midnight.

A test was devised to measure effects of disparate observation times on *DPI* values in New Mexico during the 1990 Southwest Monsoon. The test involved comparing the daily percentage of stations listed in Climatological Data of the States--New Mexico having precipitation of 0.10 inches or more to like data for stations listed in the publication, Hourly Precipitation Data--New Mexico (NOAA, 1990). The 0.10 inch threshold was required for the test since most stations listed in Hourly Precipitation Data report precipitation only in 0.10 inch increments.

The *Spearman rank correlation coefficient*, r_s , (Daniel, 1990) was used to measure the association between the two data sets. The equation for the *Spearman rank coefficient* is

$$r_s = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}, \quad \text{where } \sum d_i^2 = \sum_{i=1}^n [\text{Rank}(X_i) - \text{Rank}(Y_i)]^2.$$

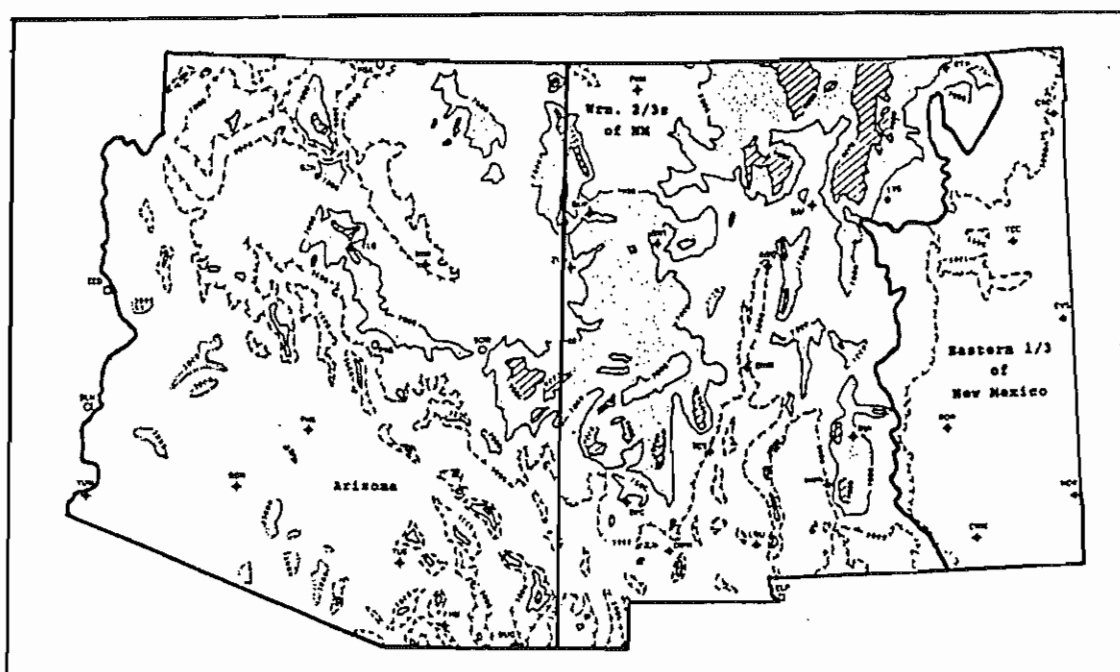


Figure 2. Topographic map of Arizona and New Mexico, showing the three zones for which Daily Precipitation Indices were derived for the 1990 Southwest Monsoon.

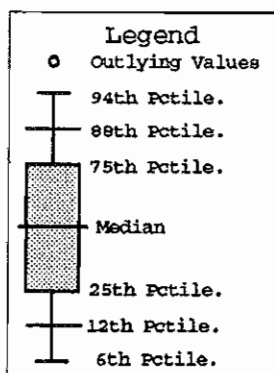
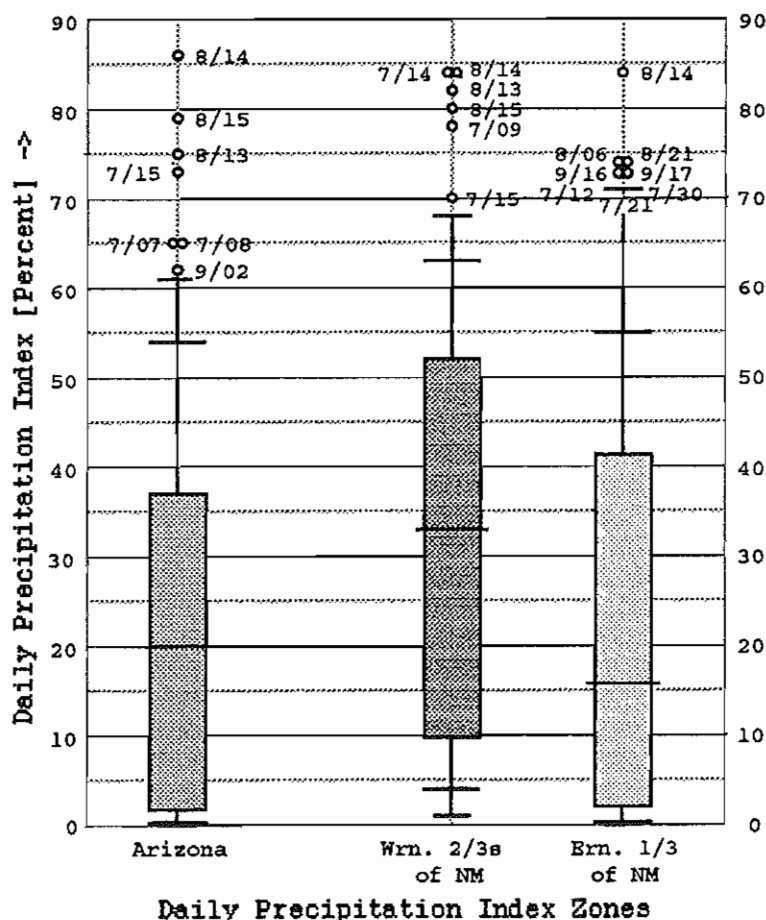


Figure 3. Box and whisker plots--one for each DPI Zone--showing the areal distributions of Daily Precipitation Indices during the 1990 Southwest Monsoon. The wettest days between 14 Jun 1990 and 26 Sep 1990 are shown as outlying values at and above the 94th percentile.



The variable n represents the number of X-Y observation pairs in the sample. Each X and Y are separately assigned ranks ranging in value from 1 to n . r_s can range in value from -1 to +1.

For the period 14 June 1990 to 26 September 1990, the Spearman rank correlation coefficient was 0.934 for the western two-thirds of New Mexico and 0.879 for the eastern one-third of New Mexico. Assuming that similar correlations exist for DPIs based on 0.01 inch thresholds, it seemed safe to use the unadjusted, or "raw," DPI values for this study.

4. Areal Distribution of Daily Precipitation Indices During the 1990 Monsoon Season

A 105 day period starting 14 June 1990 and ending 26 September 1990 was used for this study. This time interval was chosen to eliminate effects of mid-latitude storms which affected Arizona and New Mexico around 10 June and 1 October. This period adequately covers the duration of an average monsoon season in Arizona and New Mexico.

Areal distributions of Daily Precipitation Indices in the three DPI Zones are shown as *box-and-whisker plots* (Tukey, 1977) in Figure 3. These plots reveal several things about the distribution of precipitation during the 1990 Southwest Monsoon.

First, the western two-thirds of New Mexico was the wettest of the three DPI zones. Thirty-three percent or more of the stations in Western New Mexico had measurable precipitation on half the days, compared to 20 percent in Arizona, and 16 percent in Eastern New Mexico. Topography of Western New Mexico appears responsible for the higher DPI frequency: Figure 2 shows the majority of elevations above 7,000 feet are in this DPI Zone.

Second, the number of "superpeak" days (TenHarkel, 1991), that is, days with DPIs of 70 percent or more, were most frequent in New Mexico. Eastern New Mexico had eight superpeaks, compared to six in Western New Mexico, and four in Arizona.

Third, outlying values show that 14 August 1990 was the wettest day for all three DPI Zones, while the period from 13 August to 15 August was exceptionally wet in Arizona and Western New Mexico. Another superpeak day was experienced in both Arizona and Western New Mexico on 15 July.

Finally, standard deviations of the two DPI Zones in New Mexico are larger than the standard deviation of the DPI in Arizona. This may have been due to New Mexico having a greater frequency of transient disturbances or lift producing mechanisms, such as back-door cold fronts, during the period of study.

RAW AND SMOOTHED DAILY PRECIPITATION INDICES

14 JUN 1990 TO 26 SEP 1990, INCLUSIVE

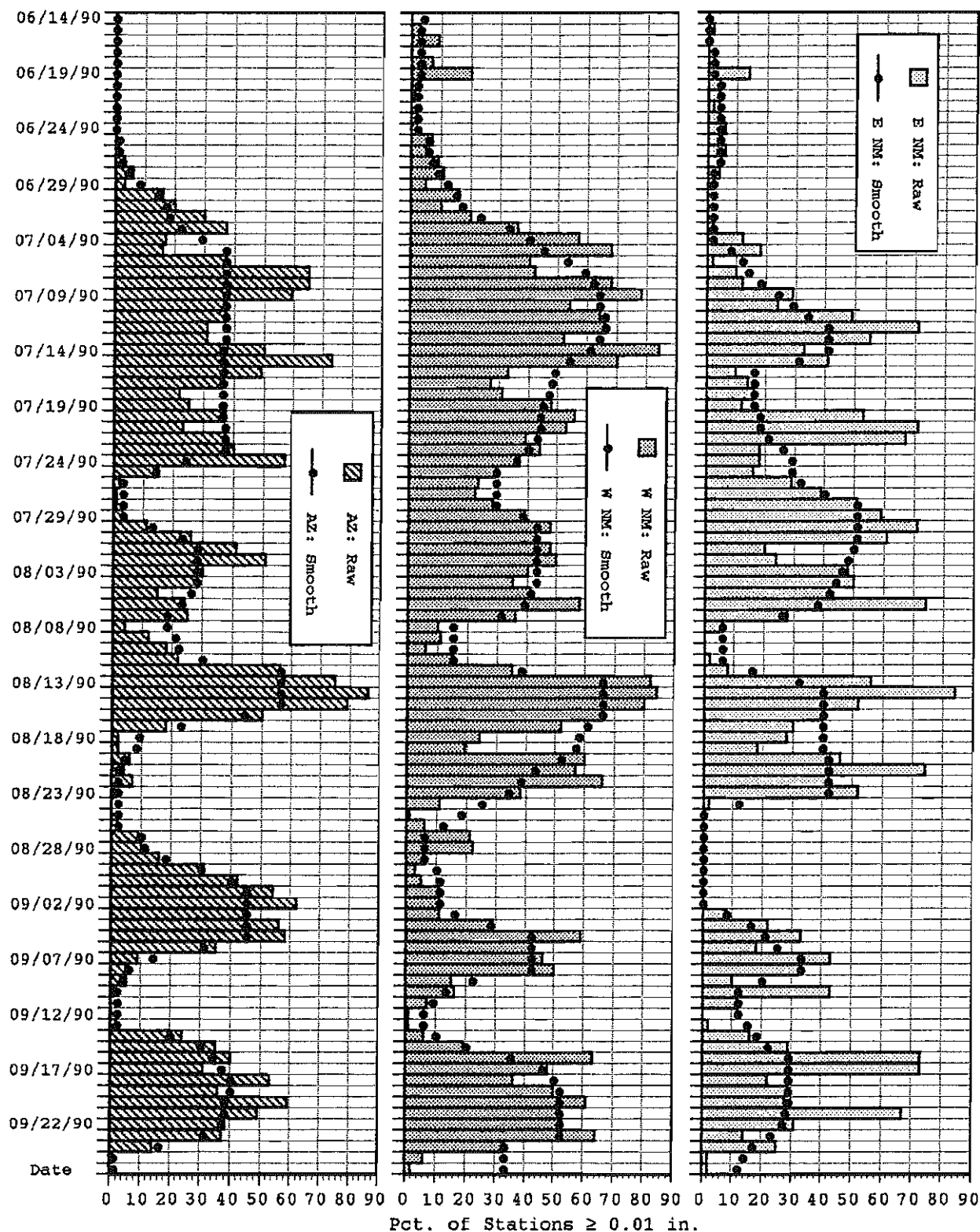


Figure 4. Bar and step charts showing the Daily Precipitation Indices from 14 June 1990 to 26 September 1990. The bar charts represent the raw DPIs in each DPI Zone, while the step charts represent smoothed DPI values.

5. Temporal Distribution of Daily Precipitation Indices During the 1990 Monsoon Season

Temporal distributions of Daily Precipitation Indices are shown in Figure 4. "Raw" Daily Precipitation Indices are displayed as bar charts--one for each DPI Zone. "Smoothed" Daily Precipitation Indices are in the form of step charts which overlay the bar graphs.

The step charts in Figure 4 were obtained by smoothing the raw DPIs. Running medians of seven (Tukey, 1977, pages 210-214), end smoothing using running medians of three (Tukey, 1977, pages 221-222), and a smoothing technique called "Hanning" (Tukey, 1977, pages 231-238) were used to produce the step charts.

The purpose of the bar charts is to display the temporal character of DPI values in each DPI Zone. The step chart was designed to filter out small-scale temporal variations and emphasize large-scale wet and dry cycles.

Figure 4 can be used to determine the onset date of the 1990 monsoon season in each DPI Zone. The season began in Arizona around 1 July, in Western New Mexico around 3 July, but was delayed in Eastern New Mexico until 9 July.

Figure 4 also reveals that 1990 monsoon type rains were not continuous, but were punctuated by several dry periods. Noteworthy breaks in the rainy season were as follows:

Arizona..	25 Jul-30 Jul,	17 Aug-29 Aug,	and	7 Sep-13 Sep;
W. NM....	8 Aug-11 Aug,	24 Aug- 4 Sep,	and	9 Sep-15 Sep;
E. NM....	8 Aug-12 Aug,	24 Aug- 3 Sep,	and	11 Sep-14 Sep.

Conversely, smoothed data reveals that the three wettest periods in each DPI zone were as follows:

Arizona..	3 Jul-24 Jul,	11 Aug-16 Aug,	and	30 Aug- 6 Sep;
W. NM....	3 Jul-24 Jul,	12 Aug-23 Aug,	and	16 Sep-24 Sep;
E. NM....	8 Jul-15 Jul,	20 Jul- 7 Aug,	and	13 Aug-23 Aug.

6. Temporal Relationship of Daily Precipitation Indices Between the DPI Zones

An attempt was made to see if any relationships in DPI values were present among DPI Zones. This was done to reveal the presence or absence of trends among DPI Zones and to show the scale of meteorological phenomena causing variation in the Daily Precipitation Indices.

Figure 5 was constructed to show potential relationships of

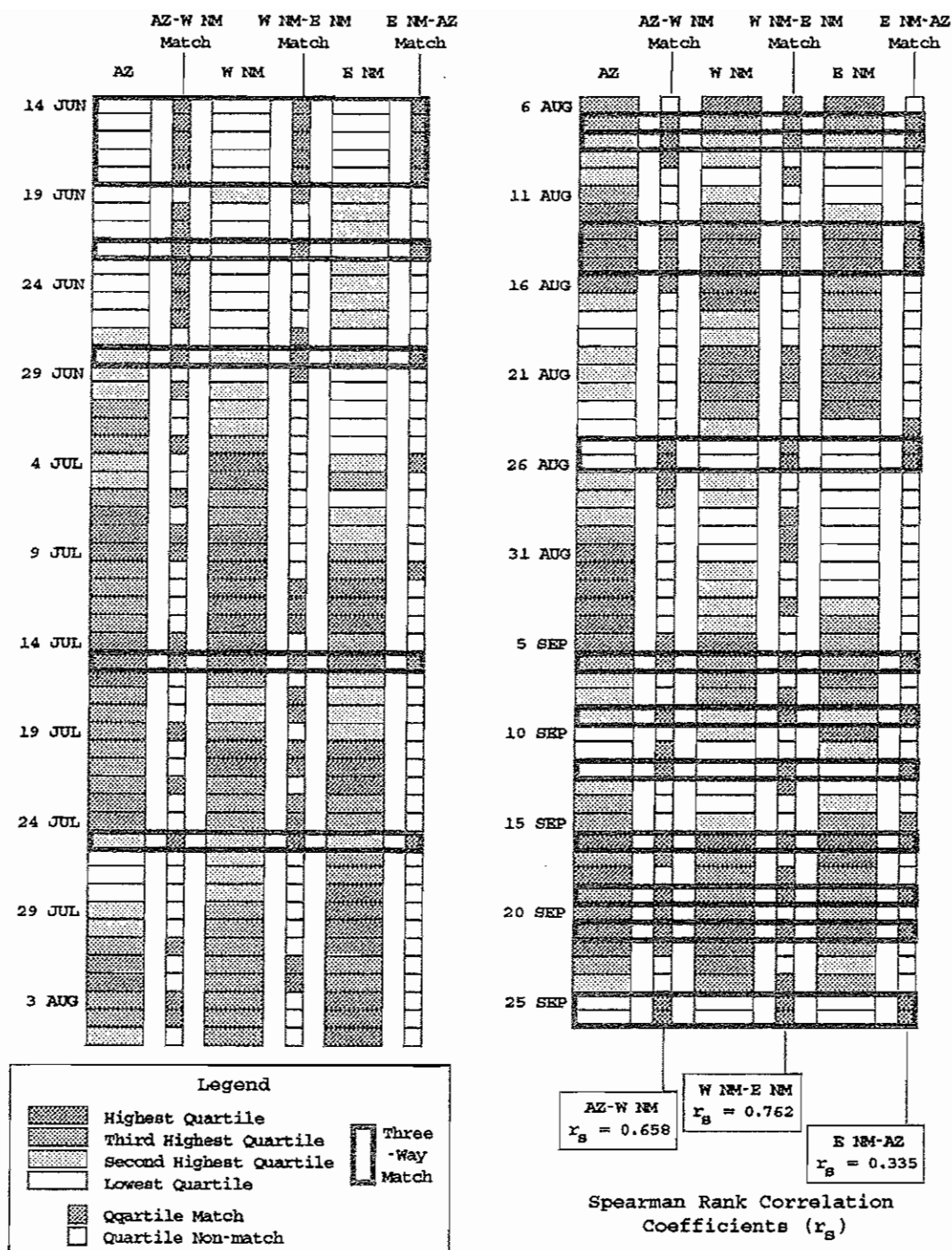


Figure 5. Custom chart showing the raw Daily Precipitation Indices arranged by DPI quartile, date, and DPI Zone. Filled-in squares are used to show quartile matches between zones. Three-way matches are indicated by bold-bordered rectangles. Spearman rank correlation coefficients (r_s) are used to measure the degree of relationship of DPIs between each pair of DPI Zones.

DPI values during the 1990 Southwest Monsoon. Figure 5 shows Daily Precipitation Indices arranged by date, DPI Zone, and quartile values of the Daily Precipitation Index. Filled-in squares are used to show quartile matches between zones; three-way matches are indicated by bold-bordered rectangles. Also, Spearman rank correlation coefficients are included to show the degree of inter-zone relationships among Daily Precipitation Indices.

Spearman rank correlation coefficients (r_s) in Figure 5 show that moderate positive correlations existed during the 1990 monsoon season between ranked DPIs in Arizona and Western New Mexico ($r_s = 0.66$) and between Western New Mexico and Eastern New Mexico ($r_s = 0.76$); only weak positive correlation existed between ranked DPIs in Arizona and Eastern New Mexico ($r_s = 0.33$). These values suggest weather systems ranging from large mesoscale to small synoptic scale affected Arizona and New Mexico during most of the period of study. An additional interpretation includes larger-scale systems which are distinctly different east and west of the Rocky Mountains, but are prohibited by topography from affecting both Arizona and Eastern New Mexico simultaneously. Twenty-four three-way quartile matches during the 105-day period of study suggest the presence of small-to-medium synoptic scale systems on these occasions.

7. Severe Weather Events

Problems associated with severe weather statistics are well known, especially in sparsely populated areas like Arizona and New Mexico. With few exceptions, you cannot observe a severe weather event unless there is an inanimate object, animal, or person that is affected by it. Also, a single severe weather report in Storm Data (NOAA, 1990) can range in size from a dust devil, microburst, or lightning strike to flash flooding which can affect several counties. Finally, conflicting accounts of severe weather events from questionable sources, such as untrained observers and erroneous newspaper reports, forces decisions on contributors to Storm Data which would cause King Solomon to throw up his hands. Based on years of working with remote sensors, I believe many severe storm events in New Mexico still manage to avoid detection.

With these thoughts in mind, I refer you to the map shown in Figure 6. This map displays all Storm Data reports of severe weather in New Mexico from 14 June 1990 to 26 September 1990. What leaps off the map is the strong correlation between severe weather and population density during the period of study. Indeed, every severe weather occurrence, except one², was located near a populated area.

² The lone exception was a severe thunderstorm detected by an automated weather station on the White Sands Missile Range.

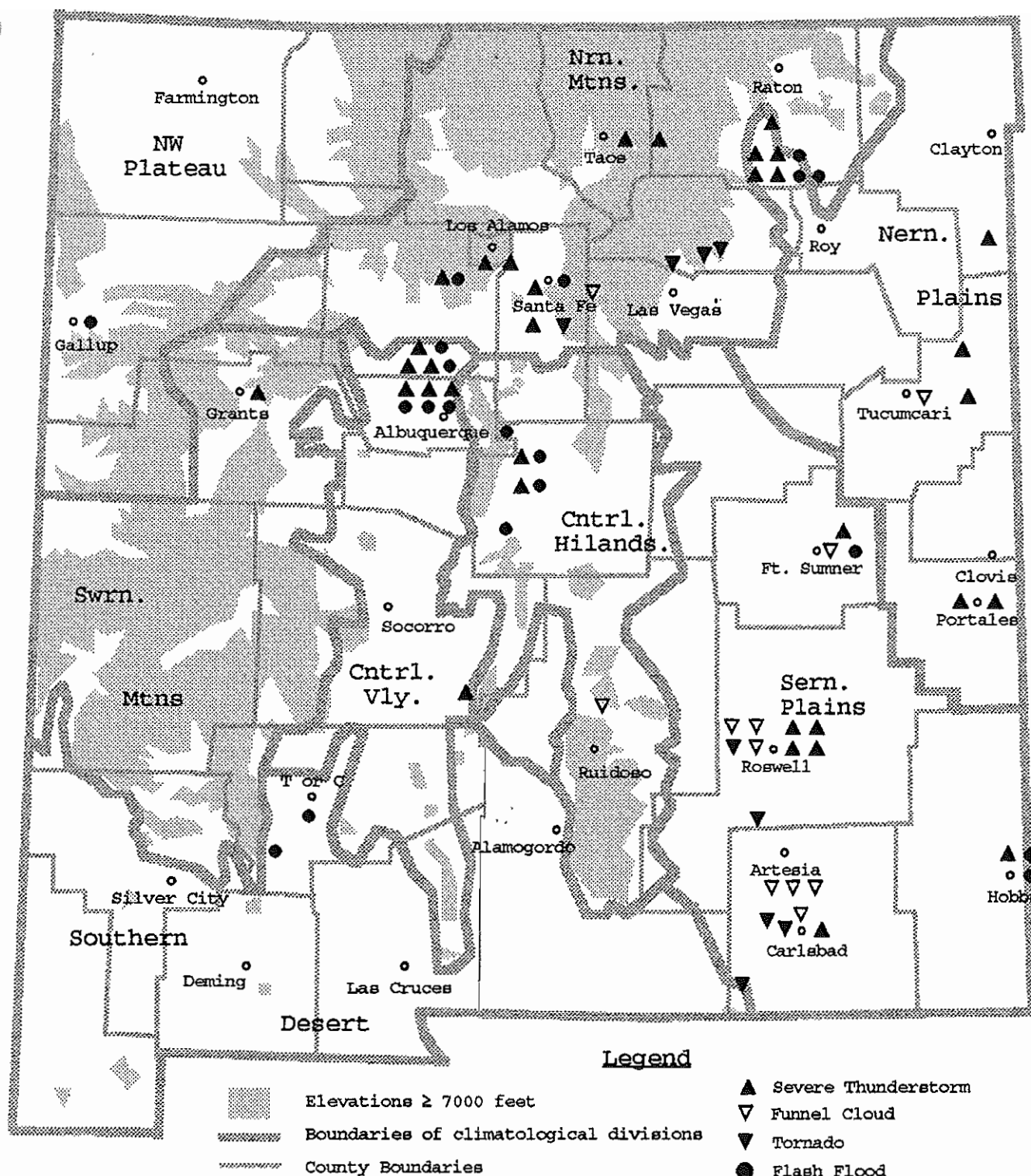


Figure 6. Location of severe storm events in New Mexico between 14 June 1990 and 26 September 1990 inclusive.

Table 1 -- SUMMARY OF SEVERE WEATHER STATISTICS
 FOR THE PERIOD 14 JUNE, 1990, TO 26 SEPTEMBER, 1990
 (r_s = Spearman Rank Correlation Coefficient)

Severe Storm Reports	Sums	DPI Vs. Svr. Stm. r_s		Severe Storm Reports	r_s
Arizona	117	0.39		AZ Vs. W. NM	0.28
Wrn. 2/3s of NM	53	0.26		W. NM Vs. E. NM	0.26
Ern. 1/3 of NM	43	0.08		AZ Vs. E. NM	0.08
Flash Flood Reports	Sums	DPI Vs. Flash. Fld. r_s		Flash Flood Reports	r_s
Arizona	39	0.50		AZ Vs. W. NM	0.24
Wrn. 2/3s of NM	16	0.29		W. NM Vs. E. NM	0.16
Ern. 1/3 of NM	10	0.25		AZ Vs. E. NM	0.21

Severe weather reports in Arizona and New Mexico were used to generate the statistics shown in Table 1. The purpose of this table was to display relationships between (1) all severe storm reports in a DPI Zone and the corresponding DPI values, (2) all flash flood reports in a DPI Zone and corresponding DPI values, and (3) severe weather and flash flood reports in different DPI Zones. Table 1 also includes the total number of severe weather events in both states during the period of study and a subtotal of flash flood events. Results evident in Table 1 are summarized below.

First, Arizona had more reports of severe storms and flash floods during the 1990 monsoon season than did New Mexico. This may be due to Arizona's larger population.

Also, DPI values and severe storm reports showed positive but weak rank correlations as did rank correlations between severe weather events in different DPI Zones. The positive, but weak, rank correlations may indicate that severe storm events in both states were small-to-medium mesoscale weather systems during the 1990 monsoon season.

8. Conclusions

July-August precipitation is very important in shaping climate in Arizona, Western New Mexico, and the Mexican states of Chihuahua, Durango, Sinaloa, and Sonora. These areas normally receive from 60 percent to 80 percent of their warm-season precipitation in these two months. Lesser percentages of warm-season precipitation are observed in Eastern New Mexico.

During the period from 14 June 1990 to 26 September 1990, Daily Precipitation Indices were highest in Western New Mexico compared to Arizona and Eastern New Mexico. Also, New Mexico had more superpeak days. SWAMP ended too soon, since the heavy rain event of 13 August through 15 August produced the highest Daily Precipitation Indices in both Arizona and New Mexico during the 1990 monsoon season. The 1990 Southwest Monsoon was interrupted in all DPI Zones by intermittent dry spells lasting several days.

Large mesoscale and small synoptic-scale weather systems appeared to be the most frequent phenomena in Arizona and New Mexico during the 1990 monsoon season, based on inter-zone correlations. On the other hand, severe weather events had weak inter-zone correlations, suggesting that most of them were small-to-medium mesoscale systems. Severe weather events were more frequent in Arizona than in New Mexico during the period of study, especially flash floods.

References

Daniel, Wayne W. Applied Nonparametric Statistics. 2nd ed. Boston: The Duxbury Advanced Series in Statistics and Decision Sciences, PWS-Kent Publishing Company, 1990.

Climatological Data--New Mexico: Vol. 94, Nos. 5-10 (May-September 1990), Asheville, NC: U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, 1990.

Hourly Precipitation Data--New Mexico: Vol. 40, Nos. 5-10 (May-September 1990), Asheville, NC: U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, 1990.

Ingram, Robert S. Arizona Summer Monsoons: True or False. Phoenix: U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service Forecast Office, Arizona NWS Technical Memorandum AZ3, 1972.

Storm Data (Entries for Arizona and New Mexico): Vol. 32, Nos. 6-9 (June-September 1990), Asheville, NC: U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, 1990.

TenHarkel, John. "The 1990 Arizona Monsoon Index," presentation given at the 1991 SWAMP Workshop, Phoenix, June 1991.

Tukey, John W. Exploratory Data Analysis. Reading, MA: Addison-Wesley Publishing Company, 1977.

Sources of Climatological Data

Arizona Climate. Tucson: The University of Arizona, Institute of Atmospheric Physics, 1960.

Atlas Climatológico de México. México, D. F.: Talleres de Gráficos, 1939.

Hastings, James R. and Humphrey, Robert R. eds. Climatological Data and Statistics for Baja California. Tucson: The University of Arizona, Institute of Atmospheric Physics, Technical Reports on the Meteorology and Climatology of Arid Regions, No. 18, 1969.

Hastings, James R. and Humphrey, Robert R. eds. Climatological Data and Statistics for Sonora and Northern Sinaloa. Tucson: The University of Arizona, Institute of Atmospheric Physics, Technical Reports on the Meteorology and Climatology of Arid Regions, No. 19, 1969.

Kunkel, Kenneth E. Temperature and Precipitation Summaries for Selected New Mexico Locations. Las Cruces, NM: New Mexico Department of Agriculture, 1983.

U. S. Department of Agriculture. Climate and Man--1941 Yearbook of Agriculture. Washington: Government Printing Office, 1941.

Weather Summary--Mexico. Washington: U. S. Navy Hydrographic Office, H.O. Pub. No. 532, 1949.

